

QED corrections in PDF fits and Photon PDFs

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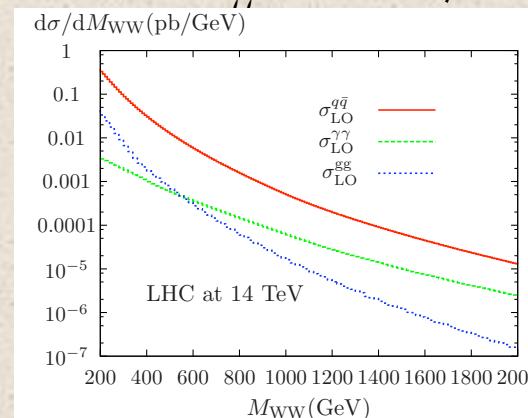
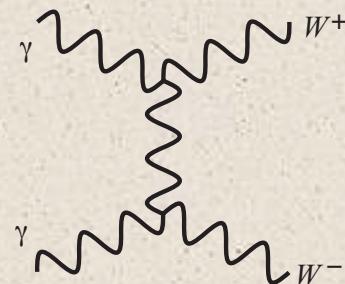
On behalf of CTEQ-TEA group

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Motivation

- 1) Sensitivity to NNLO QCD is at few % level.
 - QED and Electroweak corrections are now significant.
 - E.g., QED corrections to $pp \rightarrow W + X$ require order α effects in parton evolution
- 2) Photon induced processes can be kinematically enhanced.

$$\gamma\gamma \rightarrow W^+W^- \text{ asymptotically } \hat{\sigma}_{\gamma\gamma} \approx 8\pi\alpha^2/M_W^2$$



Bierweiler et al.,
JHEP 1211 (2012) 093

- 3) Last considered in 2004 (MRST) Martin et al., EPJC 39 (2005) 155.
 - Time for more detailed study.

This talk is a preliminary update of CTEQ-TEA activities on this topic.

Inclusion of Photon PDFs

LO QED + (NLO or NNLO) QCD evolution:

$$\frac{dq}{dt} = \frac{\alpha_s}{2\pi} (P_{qq} \circ q + P_{qg} \circ g) + \frac{\alpha}{2\pi} (e_q^2 \tilde{P}_{qq} \circ q + e_q^2 \tilde{P}_{q\gamma} \circ \gamma)$$

$$\frac{dg}{dt} = \frac{\alpha_s}{2\pi} (P_{gg} \circ g + P_{gq} \circ \sum(q + \bar{q})) \quad t = \ln Q^2$$

$$\frac{d\gamma}{dt} = \frac{\alpha}{2\pi} (\tilde{P}_{\gamma\gamma} \circ \gamma + \tilde{P}_{\gamma q} \circ \sum e_q^2 (q + \bar{q}))$$

“Radiative ansatz” for initial Photon PDFs (generalization of MRST choice)

$$\gamma^p = \frac{\alpha}{2\pi} (A_u e_u^2 \tilde{P}_{\gamma q} \circ u^0 + A_d e_d^2 \tilde{P}_{\gamma q} \circ d^0) \quad \underline{u^0, d^0} \quad \text{wavy line}$$

$$\gamma^n = \frac{\alpha}{2\pi} (A_u e_u^2 \tilde{P}_{\gamma q} \circ d^0 + A_d e_d^2 \tilde{P}_{\gamma q} \circ u^0)$$

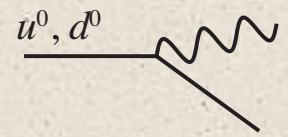
where u^0 and d^0 are “primordial” valence-type distributions of the proton.
Assumed approximate isospin symmetry for neutron.
Here, we take A_u and A_d as unknown fit parameters.

MRST choice: $A_q = \ln(Q_0^2/m_q^2)$ “Radiation from Current Mass” - CM 3

Inclusion of Photon PDFs (2)

Isospin violation occurs radiatively in u and d. To this order in α :

$$u^n = d^p + \frac{\alpha}{2\pi} (A_u e_u^2 - A_d e_d^2) \tilde{P}_{qq} \circ d^0 \quad , \quad d^n = u^p + \frac{\alpha}{2\pi} (A_d e_d^2 - A_u e_u^2) \tilde{P}_{qq} \circ u^0$$



Isospin violation in initial sea and gluon assumed negligible. $(\bar{q}^n = \bar{q}^p, g^n = g^p)$

With this ansatz, number and momentum sum rules automatically satisfied for neutron, for any choice of u^0 and d^0 .

$$i.e., \quad \sum \langle x \rangle^p = 1 \quad \Rightarrow \quad \sum \langle x \rangle^n = 1$$

Here, assume $u^0 = u^p \equiv u^p(x, Q_0)$, $d^0 = d^p \equiv d^p(x, Q_0)$

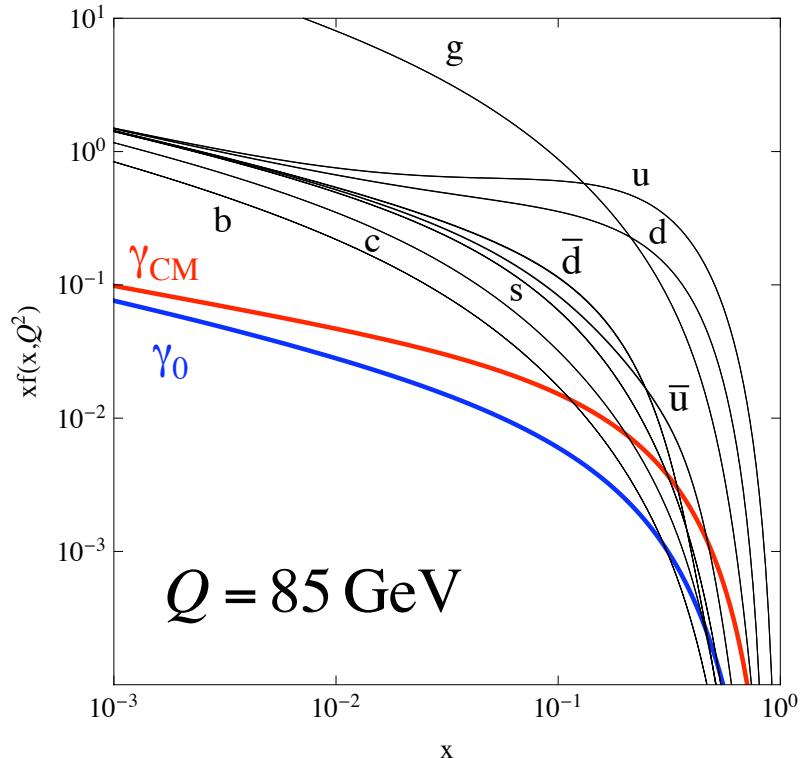
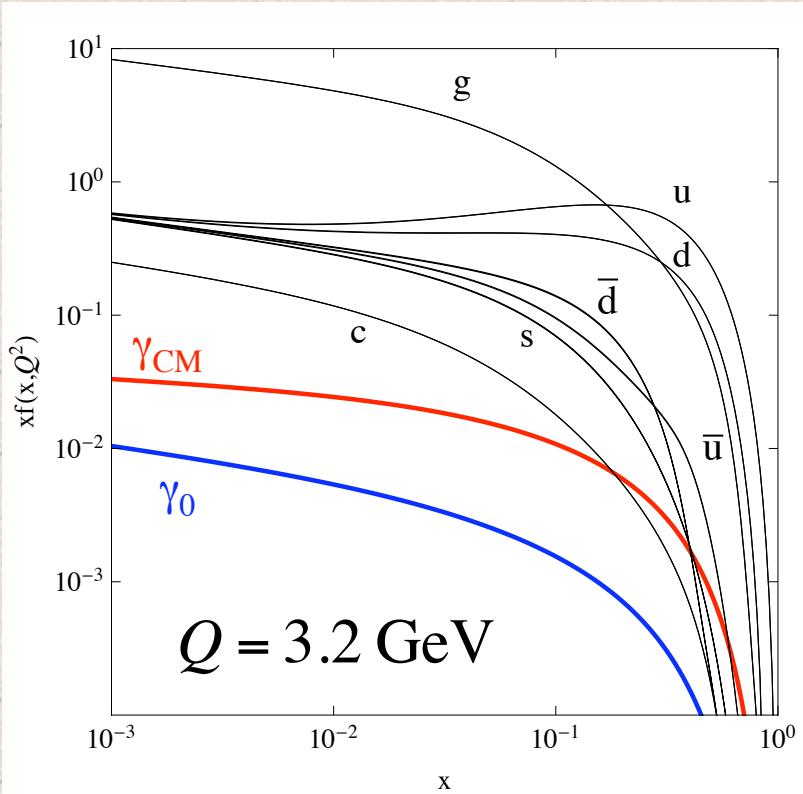
Also, let $A_u = A_0(1 + \delta)$, $A_d = A_0(1 - \delta)$

Expect δ to be small.

Now everything effectively specified by one unknown parameter:

$$A_0 \Leftrightarrow \langle x \rangle_\gamma^p \quad (\text{Photon momentum fraction})$$

Photon PDFs (in proton)



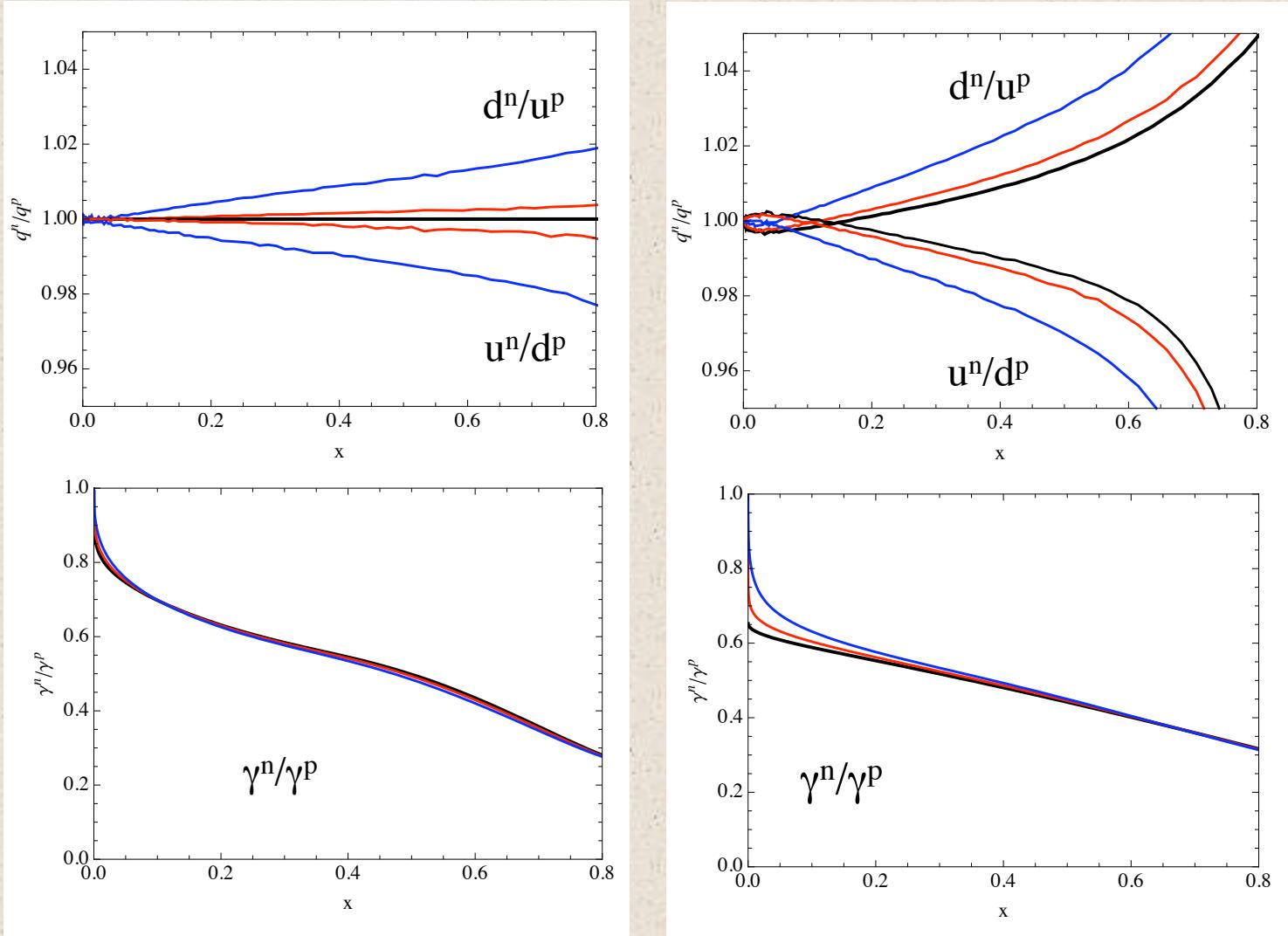
γ momentum fraction:

$\langle x \rangle_{\gamma}^p$	$\gamma^p(x, Q_0) = 0$	$\gamma^p(x, Q_0)_{\text{CM}}$
$Q = 3.2 \text{ GeV}$	0.05%	0.34%
$Q = 85 \text{ GeV}$	0.22%	0.51%

Photon PDF can be larger than sea quarks at large x !

Initial Photon PDF still
← significant at large Q .

Isospin violation



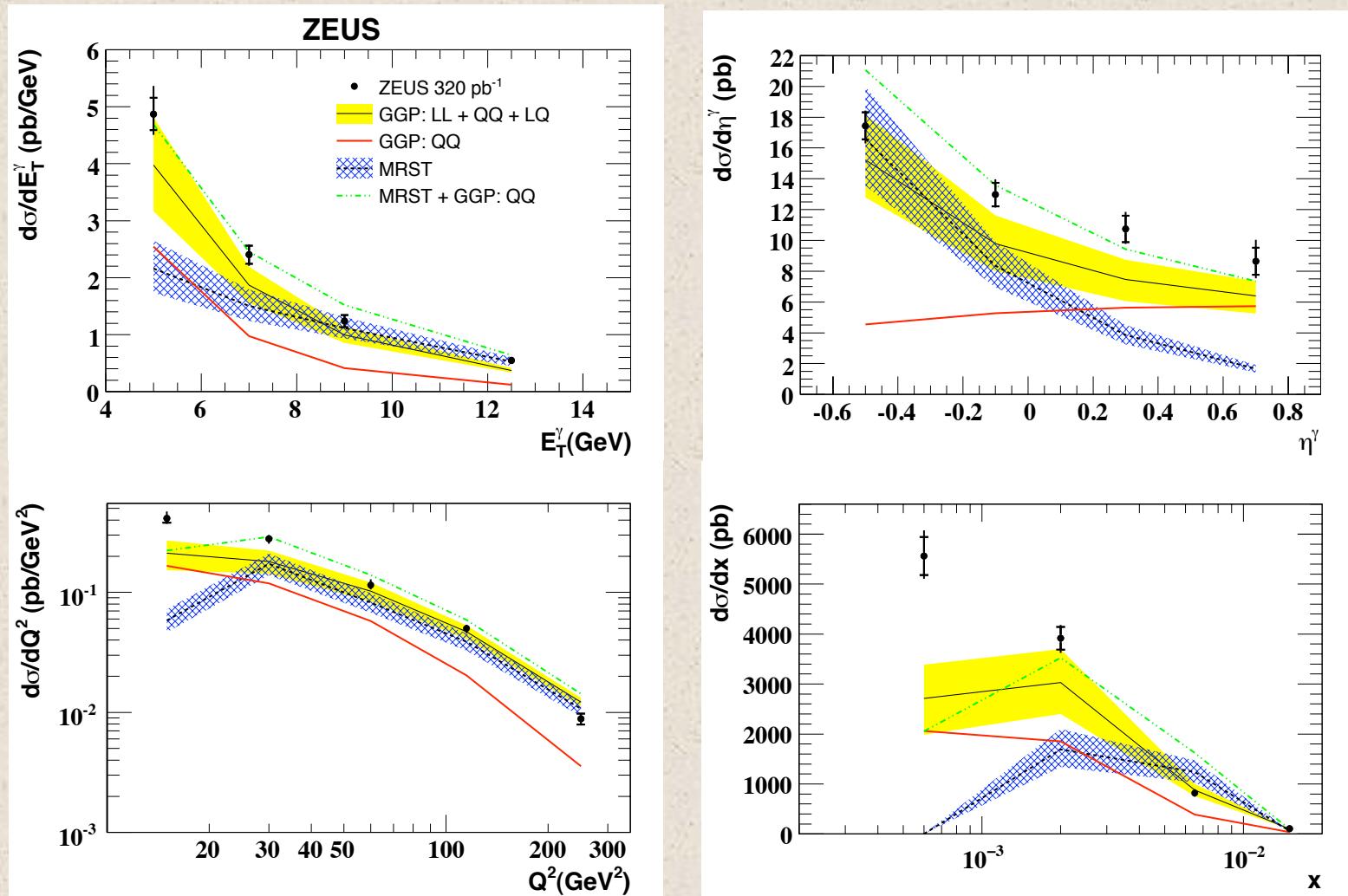
$Q=Q_0=1.3 \text{ GeV}$
 $Q=3.2 \text{ GeV}$
 $Q=85 \text{ GeV}$

$$\gamma^p(x, Q_0^2) = 0$$

$$\gamma^p(x, Q_0^2)_{\text{CM}}$$

Constraints on Photon PDFs

- 1) Global fitting
 - a. Isospin violation effects
 - come from scattering off nuclei
 - perturbativity cuts on W^2 generally require $x < .2-.4$
 - constraints likely to be small (MRST)
 - b. Momentum sum rule
 - momentum carried by photon leaves less for other partons
 - constrains momentum fraction of photon (upper bound)
 - preliminary results suggest $\langle x \rangle_{\gamma}^p$ can be as large as about $3 \times \text{CM}$ choice
- 2) Direct photon PDF probe
 - DIS with observed photon, $ep \rightarrow e\gamma + X$
 - To be included in global fit

$$ep \rightarrow e\gamma + X$$


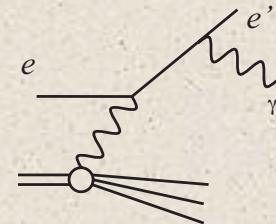
$$ep \rightarrow e\gamma + X$$

Zeus compares with two calculations:

1) Photon-initiated (MRST):

$$\text{Calculation at } (\ell'_e + k_\gamma - \ell_e)^2 = 0$$

Allows for nonperturbative $\gamma(x)$ contribution

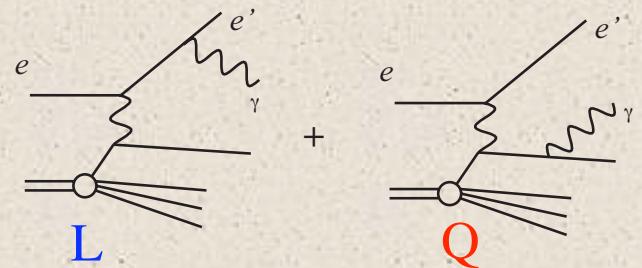


2) Quark-initiated (GGP): Gehrmann-De Ridder, et al., PRL 96, 132002 (2006)

$$\text{L requires cut } -(\ell'_e + k_\gamma - \ell_e)^2 > \mu^2$$

Q has fragmentation contribution

Both 1) and 2) are $\sim \alpha^3$ if $\gamma(x) \sim \alpha$



Consistent procedure:

$$\text{Treat as NLO in } \alpha \text{ with } \gamma^{\text{bare}}(x) = \gamma(x) + \frac{(4\pi)^\varepsilon}{\varepsilon} \Gamma(1+\varepsilon) \frac{\alpha}{2\pi} (P_{\gamma q} \circ q)(x) \quad (\text{MSbar})$$

Both 1) and 2) contribute.

Divergence in **L** cancels (integrate over full phase space in $d=4-2\varepsilon$).

Reduced factorization scale μ_F dependence.

Use to fit $\gamma(x)$

Conclusions

- Theory:
 - Presented framework for including QED effects and $\gamma(x)$ in PDFs
 - With reasonable assumptions, one dominant fitting parameter, $\langle x \rangle_{\gamma}^p$
- Data:
 - Global analysis, and in particular, process $ep \rightarrow e\gamma + X$ should constrain $\gamma(x)$
- Predictions:
 - QED evolution essential for consistent treatment of EW corrections:
eg. W-lepton asymmetry
 - $\gamma(x)$ required for photon-initiated processes:
eg. $\gamma\gamma \rightarrow W^+W^-$